SATELLITE LINK DESIGN

ECE 514E-RADAR & SATELLITE ENGINEERING

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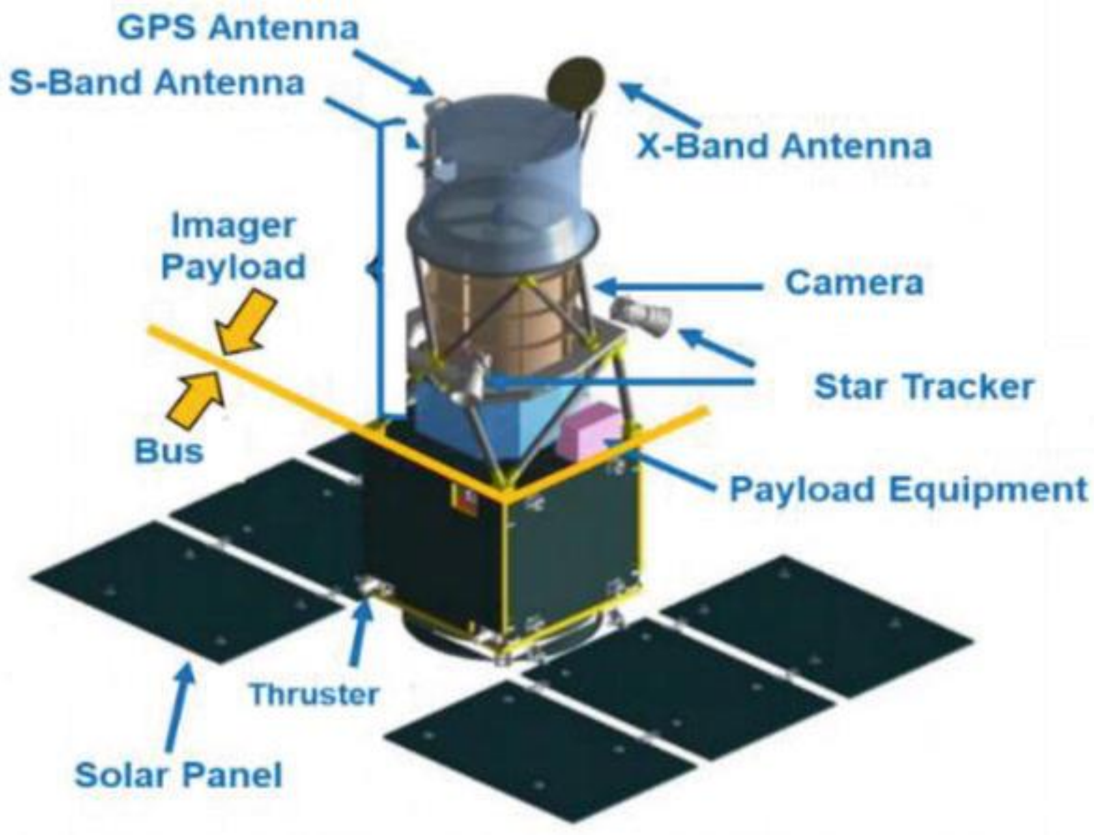
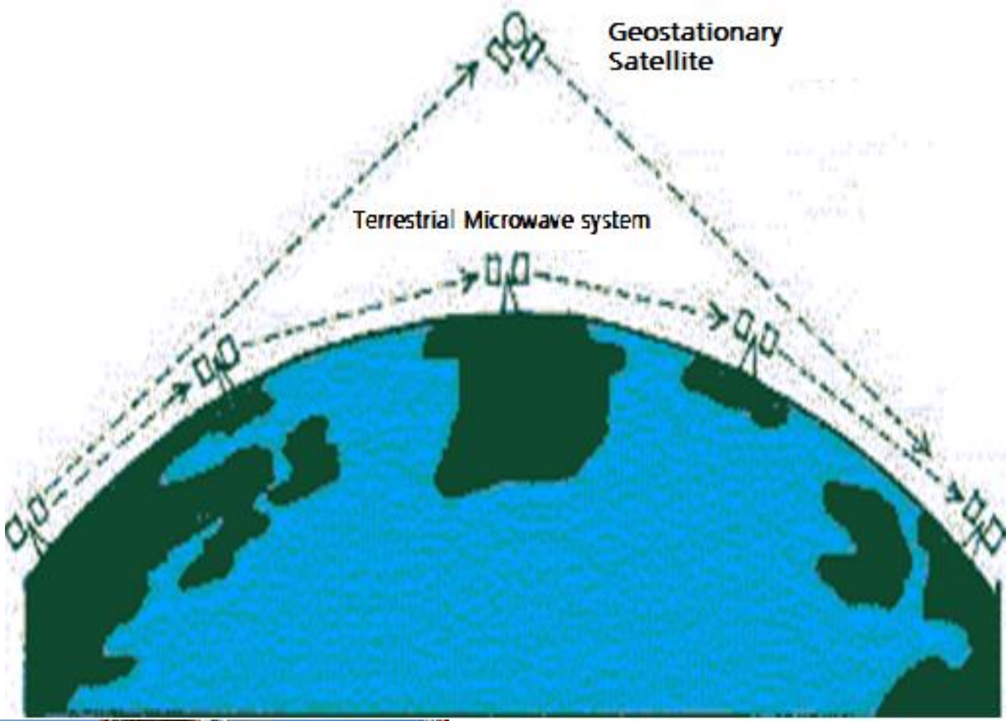
DESIGN OF SATELLITE COMMUNICATION SYSTEMS

1. Dominant factors in the design of a communication satellite system are:
   a) Weight of satellite
   b) DC power generated on board
   c) Frequency allocation
   d) Multiple access techniques employed
2. Weight of satellite affects the launch costs currently standing at over US$100,000 (Ksh. 13 million) per Kg.
3. Requirement for small weight limits the size of the solar cells and size of antenna as a result, the satellite has limited RF output and consequently low signal.



SATELLITE LINK

1. **A satellite link is a radio relay link and** is similar to terrestrial microwave links with the exception that it does not terrestrial repeater stations and the link is longer.
2. Both satellite links and terrestrial microwave links require Line of Sight (LOS) paths, i.e the use space-wave and nit skywave propagation.
3. Theoretically 3 geostationary satellites can achieve global coverage while terrestrial microwave stations may require as many as 10 repeater stations for a 500 km stretch, e.g Mombasa to Nairobi.




(a) Terrestrial Microwave links


(b) Earth Station

SATELLITE COMMUNICATION SYSTEM DESIGN

Optimal satellite communication system design can be divided into two categories:

i.Conduit design:

a)Signal path;

b)Signal propagation

c)Earth Station Equipment

d)Satellite antenna design

ii.Transmission and Multiplex systems:

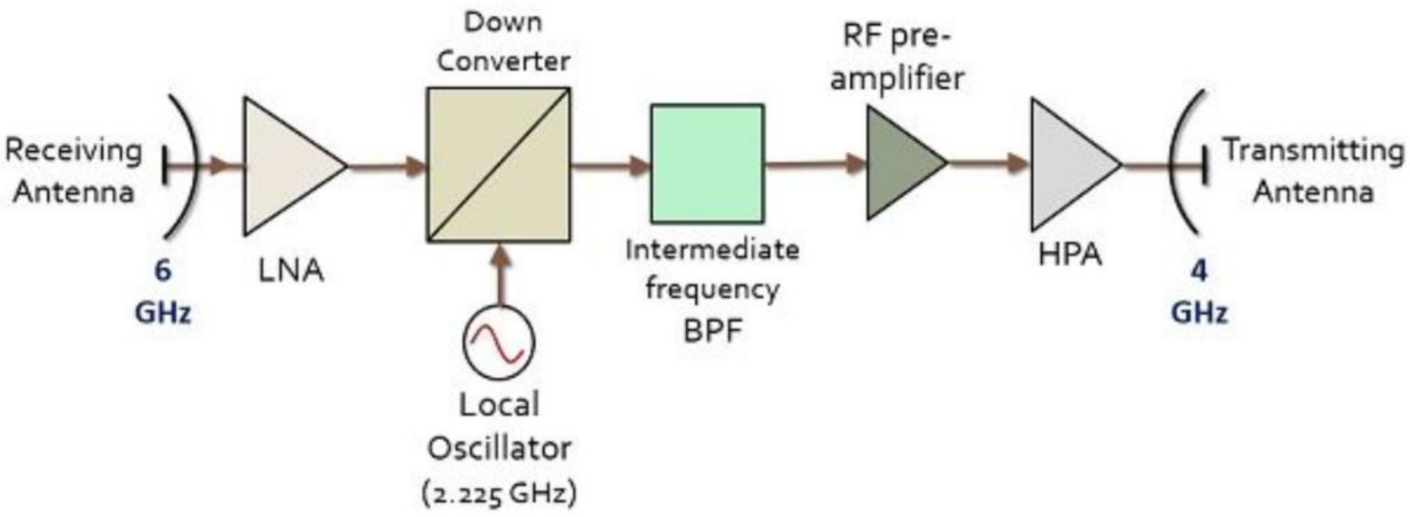
a) Multiplex techniques

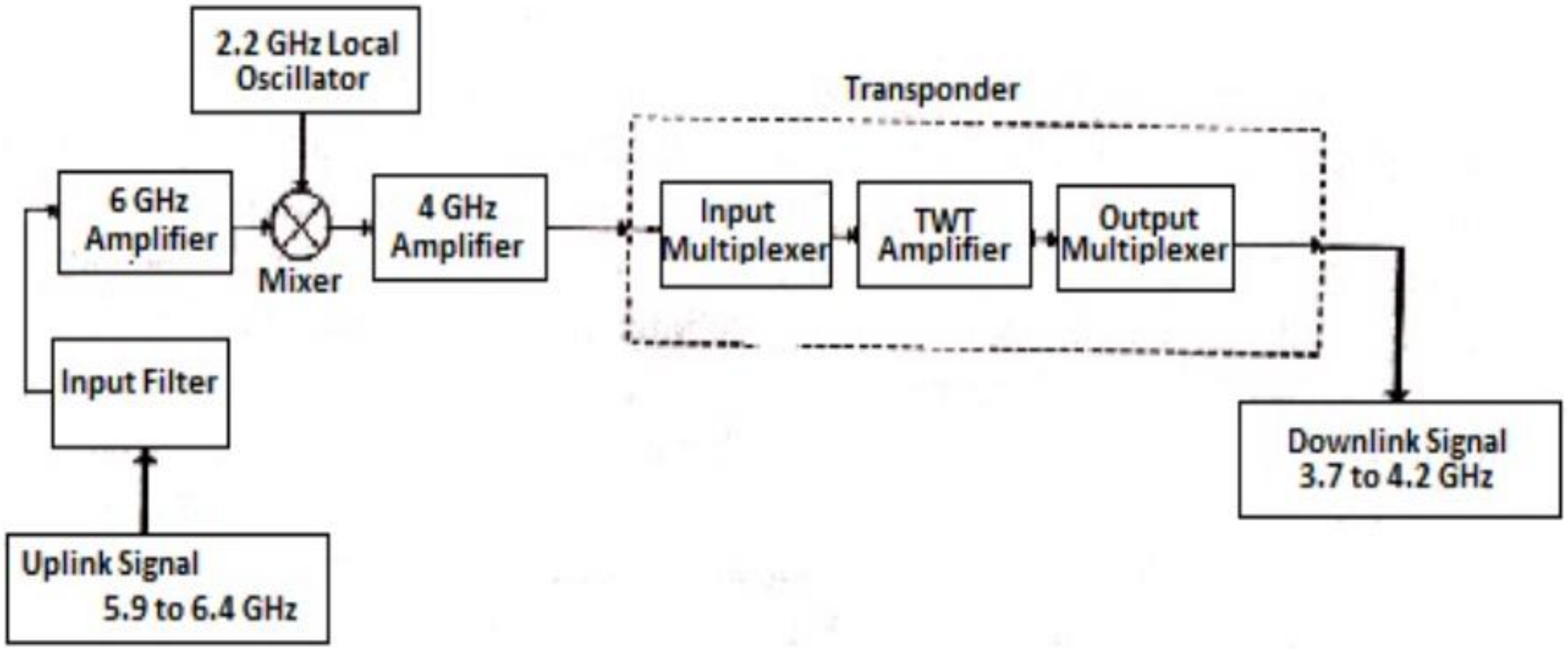
b) Telecommunication interface

c) Data protocols, etc

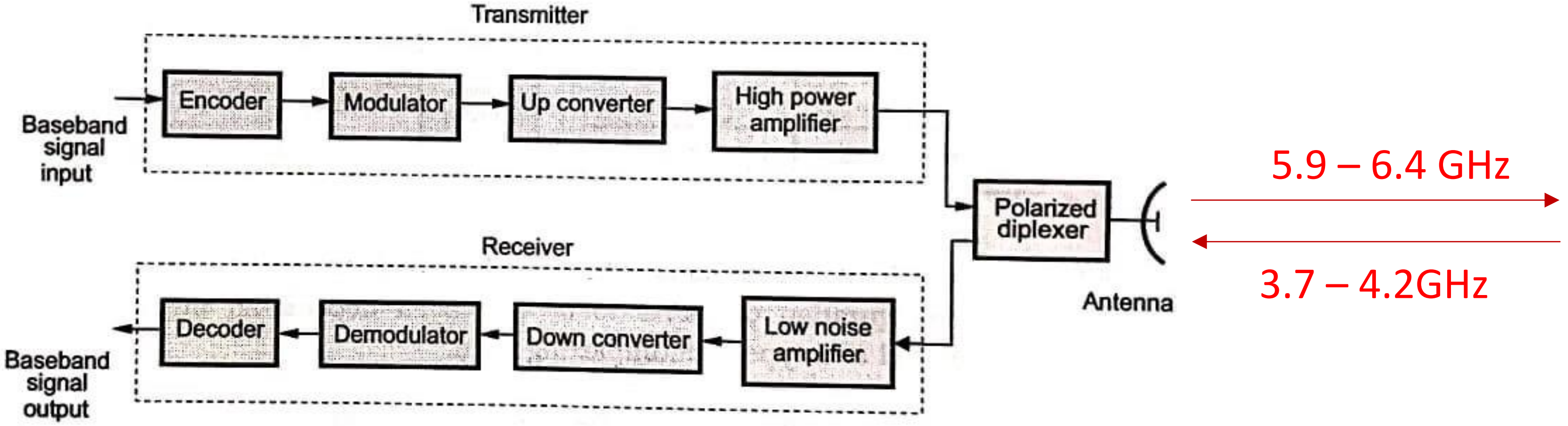
RECAP: TRANSPONDER DEFINITION

1. **A Transponder** is a wireless communications, monitoring, or control device that picks up and automatically responds to an incoming signal.
2. The term is a contraction of the words **Trans**mitter and Res**ponder**.
3. Transponders can be either passive or active.
4. **Passive transponders** are also called **bend-pipe transponders**.
5. Modern satellites use active transponders.





(a) Block Diagram of Satellite C-band Communication Subsystem



(b) Basic Block Diagram of an Earth Station

Why uplink frequency is higher than the downlink?

1. Attenuation increases with frequency.
2. The satellite is more handicapped than the ground station in terms of power.

SATELLITE TRANSPONDER

1. **A transponder is a broadband RF amplifier and repeater** used to amplify one or more carriers on the downlink side of a geostationary communications satellite.
2. It forms part of the microwave repeater and antenna system that is housed on the satellite.
3. In the C and Ku band, each transponder uses a traveling wave tube amplifier (TWTA) or a solid-state power amplifier (SSPA).
   a) Satellites of this type are very popular for transmitting TV channels to broadcast stations, cable TV systems, and Direct to the home TV.

SATELLITE DATA RATES

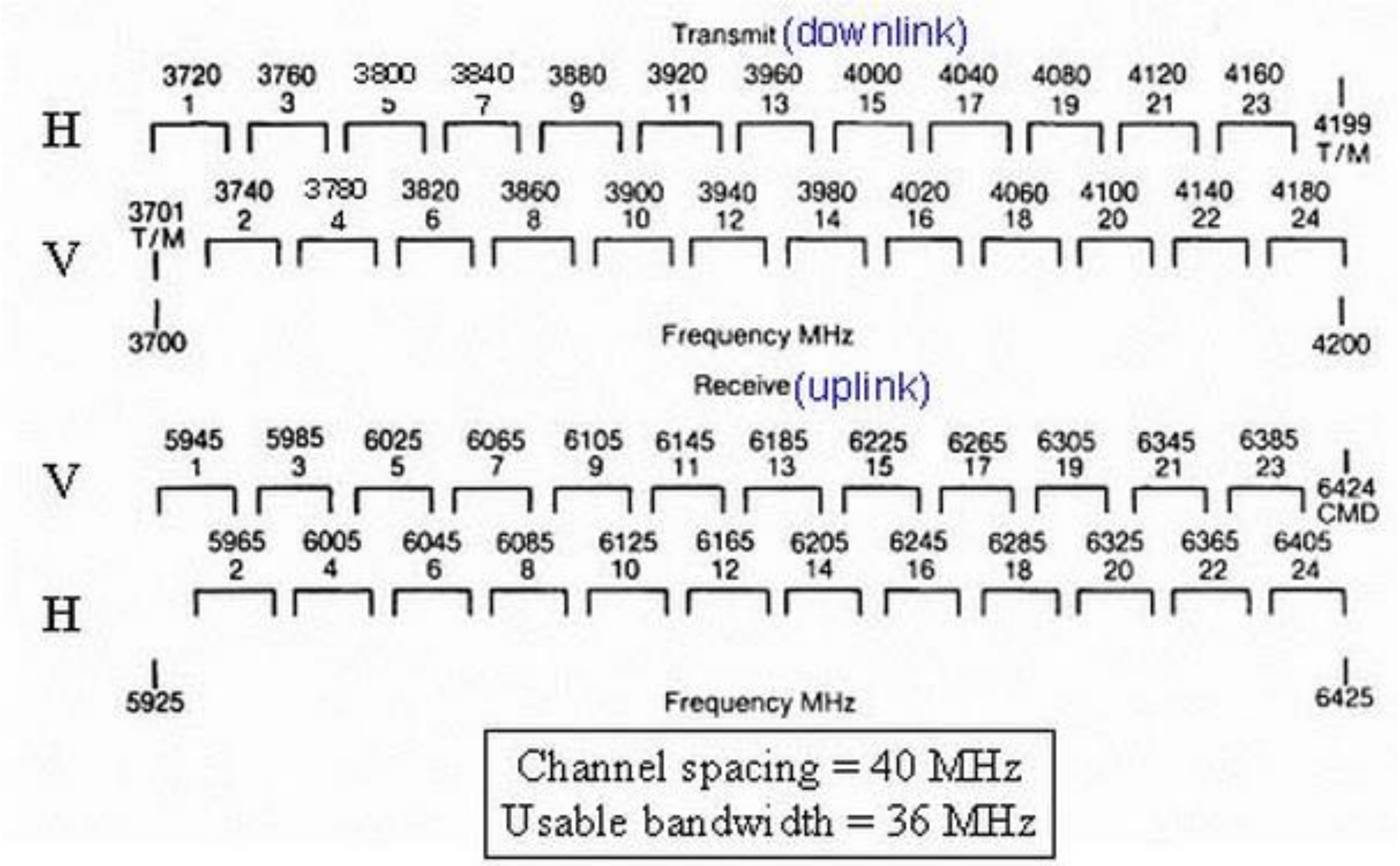
SYSTEM / SERVICE TYPE	TYPICAL DATA RATES (DOWNLINK / UPLINK)	PRIMARY APPLICATIONS / CONTEXT
Starlink (Residential)	25-100+ Mbps	General home broadband, especially in rural/remote areas.
Starlink (with BBR Algorithm)	**Dramatic improvements** ~10 x to 18x	Demonstrates impact of advanced networking software on throughput over lossy satellite links.
OneWeb (Quoted User Rate)	~50 Mbps per user	Targeted at enterprise, government, and community connectivity (e.g., backhaul for cell towers).
Telesat Lightspeed (Enterprise)	Up to 370 Mbps / 110 Mbps	High-performance backhaul for 5G, maritime, aero, and public safety networks.
Intelsat (Gov. Services)	Up to 250 Mbps (downlink)	Mission-critical communications for government and defense on-the-move/pause

BBR (Bottleneck Bandwidth and Round-trip propagation time) is a congestion control algorithm for TCP (Internet Protocol) developed by Google.

SATELLITE TRANSPONDER ../1

1. A transponder takes in the signal from the uplink at a frequency f_1, amplifies it and sends it back on a second frequency f_2.
2. The figure shows a typical frequency plan of a 24-channel C-band transponder using vertical and horizontal polarization.
3. The uplink frequency is at 6 GHz, and the downlink frequency is at 4 GHz.
4. The are 24 FDM channels of 40 MHz bandwidth with 4MHz guard band.

A TYPICAL FREQUENCY PLAN FOR A C-BAND STATELLITE SYSTEM



SATELLITE LINK DESIGN DEFINITION

Satellite link design is an estimation of power that should be transmitted from the earth station to the satellite and from satellite towards the earth station so that the signal can be detected at the receiver.

FRIIS TRANSMISSION EQUATION /01

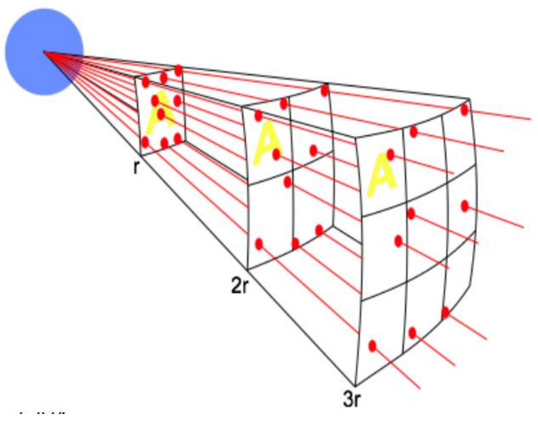
1. Consider a source located in free space and radiating power P_T watts in all directions.
2. The power of the signal is spread over a wave front, the area of which increases as the distance from the transmitter increases. Therefore, the power density diminishes as shown.
3. An isotropic source is not practically possible as it amounts to creating transverse polarized electromagnetic waves.
4. In practice, directional antennas with gain G_T are used.
5. The flux density in the direction of the antenna boresight at a distance R is therefore given by:

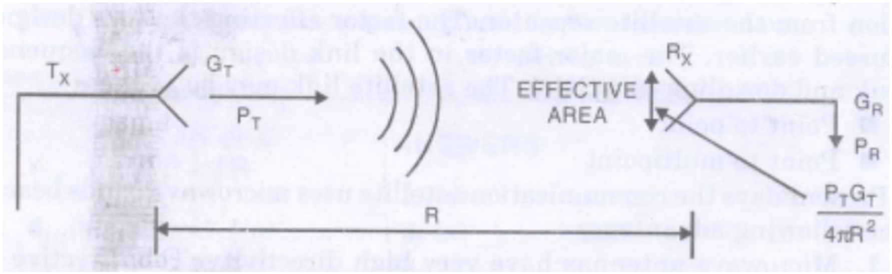
$$F = \frac{P_T G_T}{4\pi R^2} \; W/m^2$$

6. $P_T G_T$ is the **Effective Isotropic Radiated Power (EIRP)** and is a measure of the power flux.
7. At the receiving antenna, the received power is given by:

$$P_R = \eta A_R F = \eta A_R \frac{P_T G_T}{4\pi R^2} = \frac{P_T G_T A_e}{4\pi R^2}$$

Where η is the aperture efficiency of the antenna, A_R is the area of receiving antenna and A_e is effective aperture.





FRIIS TRANSMISSION EQUATION /02

8. The gain of the receiving antenna is given by:

$$G_T = \frac{4\pi A_e}{\lambda}$$

Substituting, we get

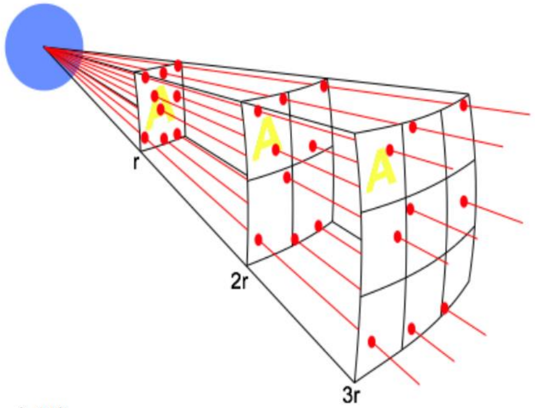
$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi R}\right)^2$$

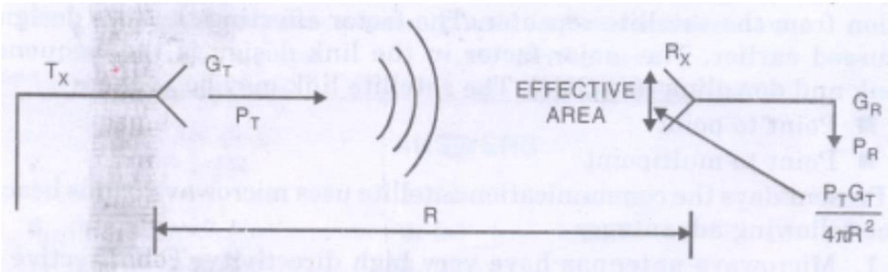
9. This equation is known as the Friis Transmission equation.

10. can be written as:

$$Power\ Received = \frac{EIRP\ \times Received\ Antenna\ Gain}{Path\ Loss}$$

Where Path loss = $\left(\frac{4\pi R}{\lambda}\right)^2$ and Effective Isotropic Radiated Power (EIRP) = $P_T G_T G_R$





EXAMPLE

1. A satellite transponder operating at a downlink frequency of 12 GHz transmits power at 20 W. If the antenna gain is 45 dB, calculate the EIRP in dB_W.

SOLN:

$EIRP = 10log_{10}20 + 45 = 58$ dBw

EXAMPLE 2

1. A satellite at a distance of 39,000 km from the earth station radiates a power of 20 W from an antenna with a gain of 22 dB in the direction of a VSAT with an effective aperture area of 10 m^2. Find:
   a) The flux density at the earth station
   b) The power received by the VSAT antenna
   c) If the satellite operates at a frequency of 11 GHz and the Earth Station (ES) antenna has a gain of 52.3 dB. Determine the received power in dBW.

SOLN:

Satellite antenna gain = 22 dB = $10^{22/10}$ = 158.5

Satellite signal wavelength, $\lambda = \frac{c}{f} = \frac{3\times10^8}{11\times10^9} = 0.273$

Earth station to satellite distance, R=39,000 km = $3.9\text{x}10^7$ m

(a) Flux Density is given by:

$$F = \frac{P_T G_T}{4\pi R^2} = \frac{20\times158.5}{4\times\pi\times(3.9\times10^7)^2} = 1.66\times10^{-13}\ \text{W/m}^2$$

(b) Power received at the VSAT antenna is given by:

$$P_r = F\times A_e = 1.66\times10^{-13}\times10 = 1.66\times10^{-12}W$$

(c) $$L_p = 20log\left(\frac{4\pi R}{\lambda}\right)=20log\left(\frac{4\pi\times3.9\times10^7}{0.0273}\right) = 205.08\ dB$$

$$P_R = EIRP + G_r - L_p = 35.01 + 52.3 - 205.08 = -117.77\ dBW$$

SATELLITE SIGNAL ATTENUATION

1. Loss in the link equation is composed of:

   a) atmospheric losses due to air, rain and water vapour

   b) Losses in the antenna at each site

   c) reduction in antenna gain due to antenna misalignment.

2. These are usually incorporated in the antenna loss equation as follows:

$$P_R = EIRP + G_T - (sum\ of\ all\ attenuation)$$

RECEIVER NOISE TEMPERATURE

1. **Noise temperature** determines the thermal noise generated by devices in the receiver.
2. The most significant source of noise in the receiver is thermal noise in the pre-amplifier.
3. Noise power P_N in the receiver is given by:

$$P_N = KT_B B$$

Where: K is the Boltzmann constant =1.36 x 10^{-23}

T_n = Receiver noise temperature

B = Bandwidth

4. The noise spectral density is constant for all radio frequency in the range 0 - 300GHz.
5. The intermediate frequency amplifier is usually designed to be large enough to pass the signal while restricting the noise bandwidth, B.
6. If G is the gain of receiver before demodulation, the **carrier to noise ratio** is given by:

$$\frac{C}{N} = \frac{P_R G}{KT_B BG} = \frac{P_R}{KT_B B}$$